Dust Grains & Debris Discs

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Outline

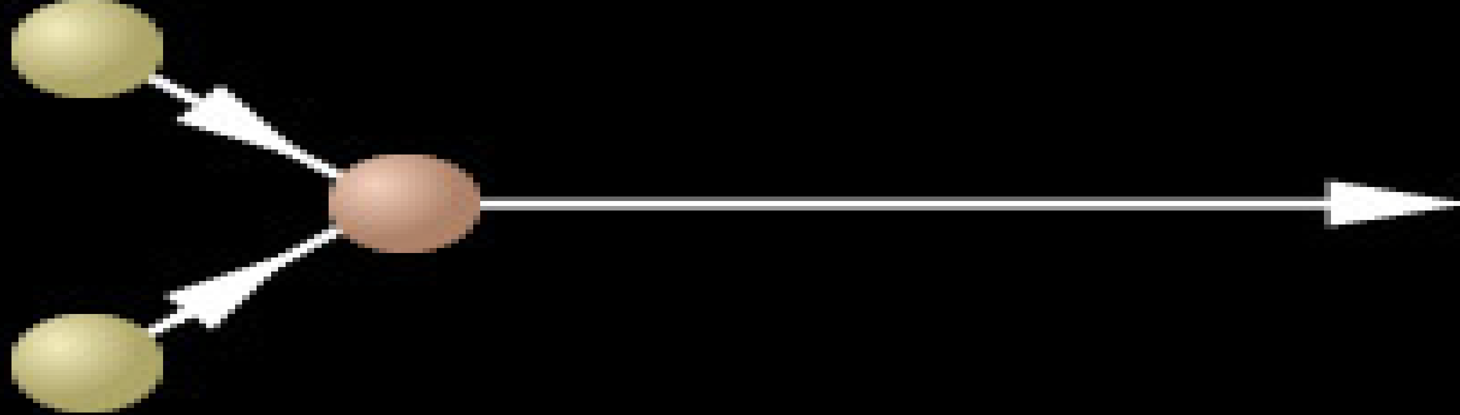
- Debris Discs
- Spitzer Results on the Vega
- Results in
  Jiang & Yeh (2009)
- The Vega Puzzle
- Recent Results

The Vega & Debris Disc

- The Vega, one of the brightest nearby stars, typical example with a dust disc
- Vega-like stars: with dust disc (IR excess)
- Debris discs are the dust discs around Vega-like stars
- Dust grains produced by collisions of km-sized planetesimals

The Formation of Debris Disc

- Dust grains collide and stick to form larger bodies
- Further growth into asteroid or proto-planets enormously
- Planetesimals may grow or break

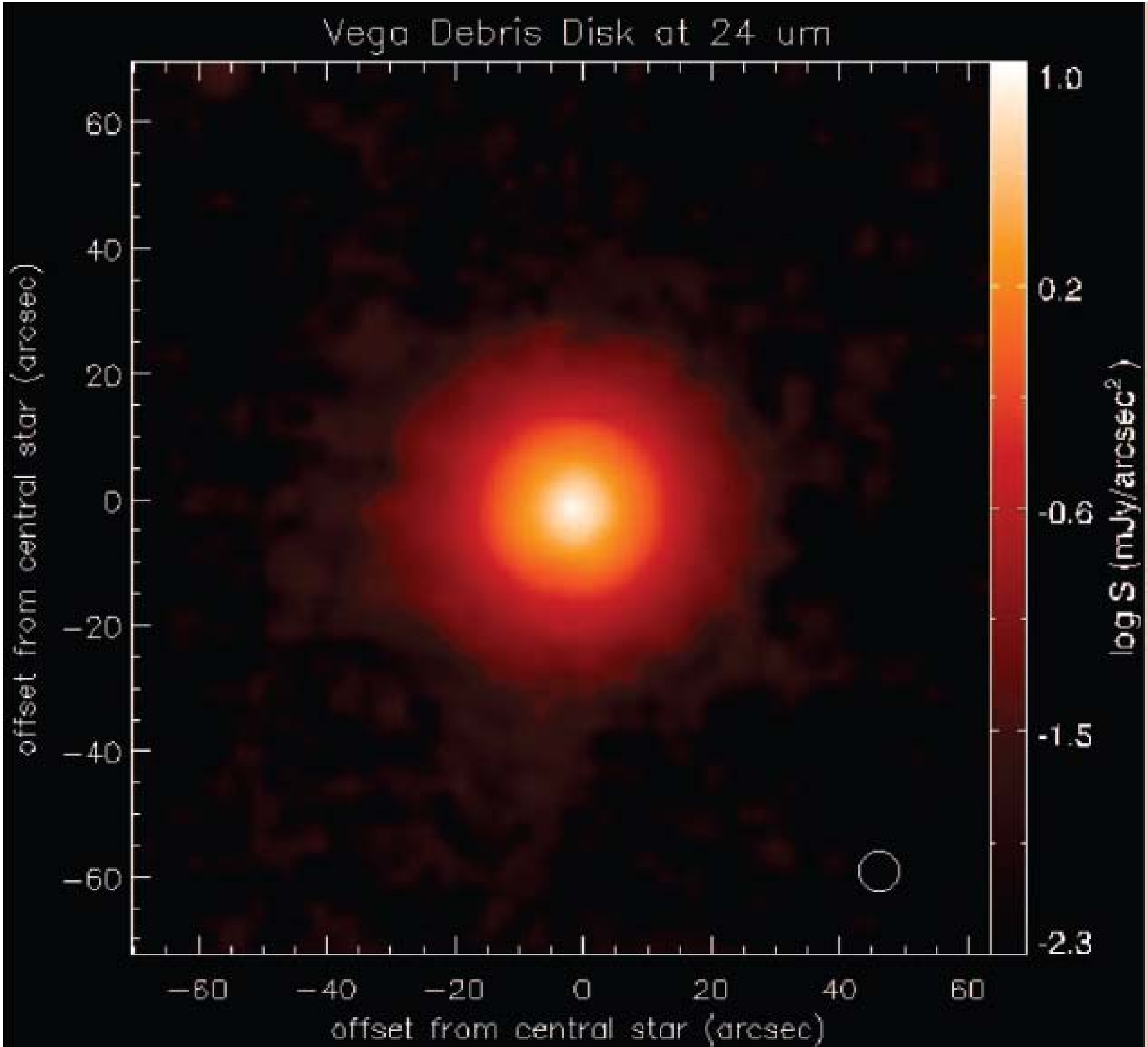


Oblique collisions → regular orbits

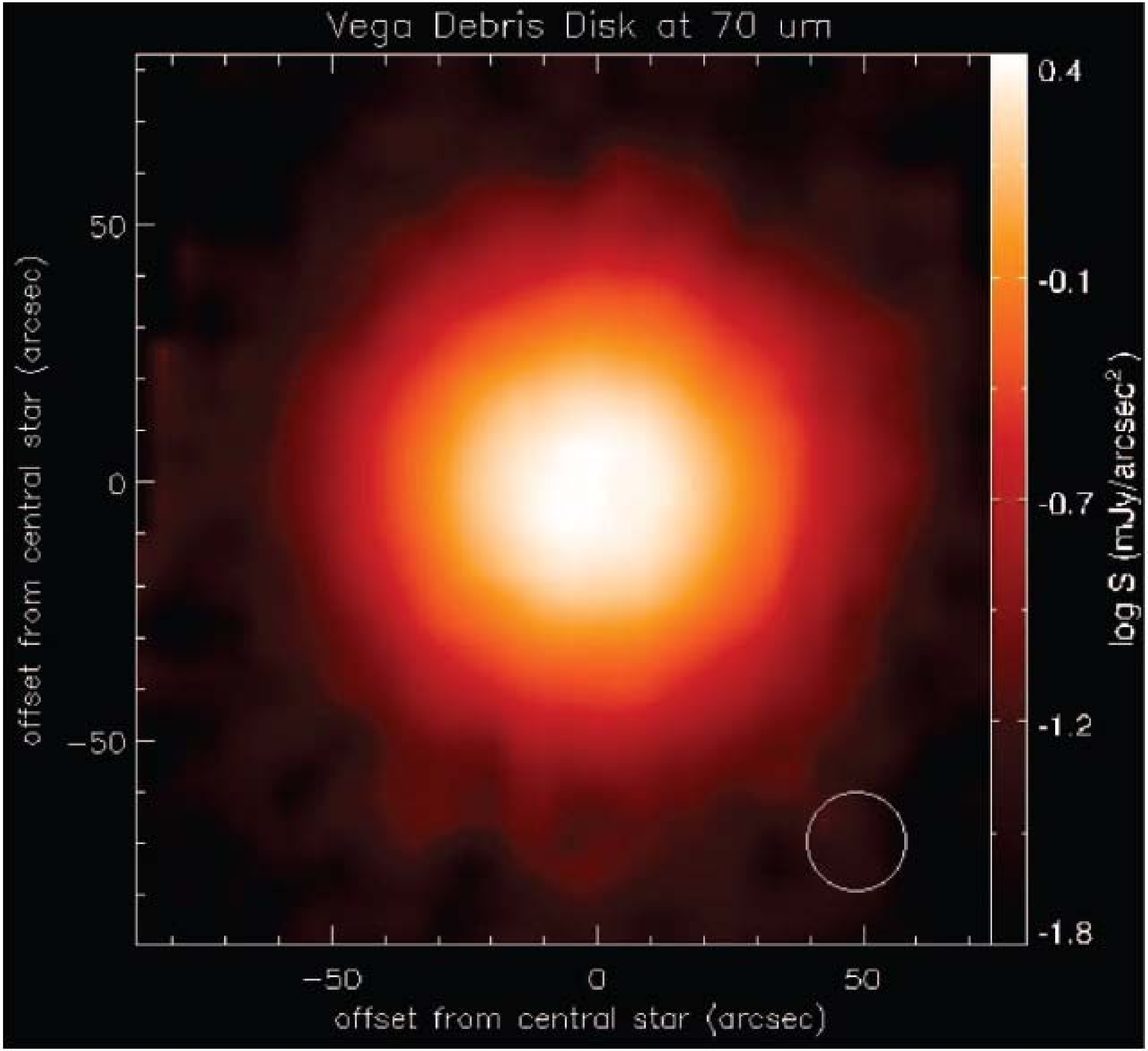
Head-on collisions → smaller object

Planetesimals v.s. Dust Grains

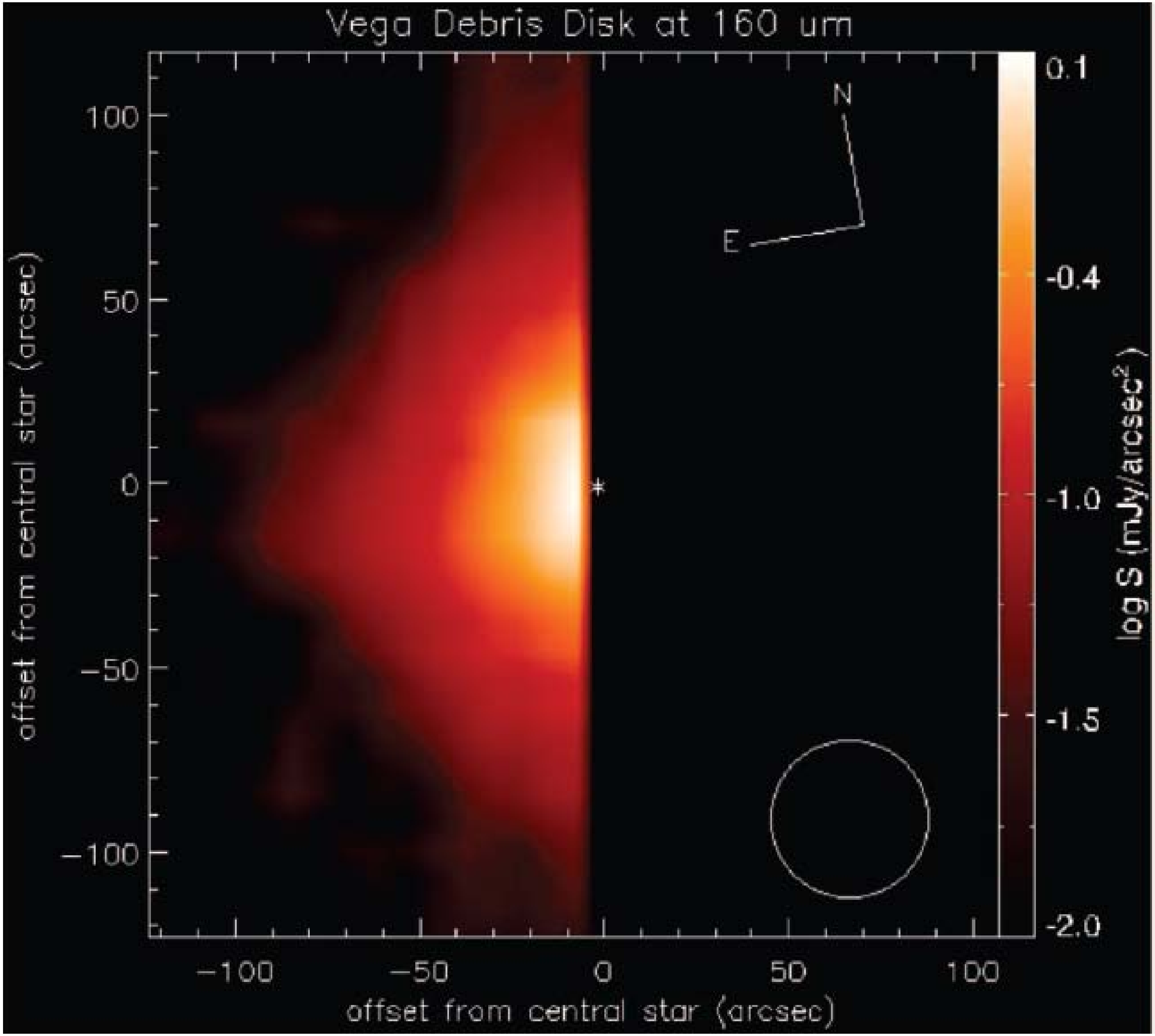
- The planetesimals cannot be observed
- Dust grains can be observed by infrared
- The observational data of dust grains can help us to understand the planetesimals
- Spitzer’s images on Vega’s debris disc: Su et al. (2005)



Vega Debris Disk at 24 um
offset from central star (arcsec)
60
40
20
0
−20
−40
−60
−60
−40
−20
0
20
40
60
offset from central star (arcsec)
1.0
0.2
-0.6
-1.5
-2.3
log S (mJy/arcsec^2)



Vega Debris Disk at 70 um
50
0
-50
-50
0
50
offset from central star (arcsec)
offset from central star (arcsec)
0.4
-0.1
-0.7
-1.2
-1.8
log S (mJy/arcsec^2)


Vega Debris Disk at 160 um
N
E
offset from central star (arcsec)
offset from central star (arcsec)
log S (mJy/arcsec^2)
100
50
0
−50
−100
−100
−50
0
50
100
0.1
-0.4
-1.0
-1.5
-2.0

Su, Rieke et al. (2005)

- At R > 200 AU, surface density: 1/R profile (assume a uniform size distribution)
- A ring of planetesimals and asteroids between 86 and 200 AU
- The ring region produces new dust grains
- Dust grains are blown out
- We witness a recent event !

Questions

- How could large grains be far away ?
- What is the effect of chemical compositions ?
- What is the effect of grain-size cut-off ?
- How frequently the collisions shall be ?
- Does the self-consistent dynamical blowing-out picture exist ? We shall check

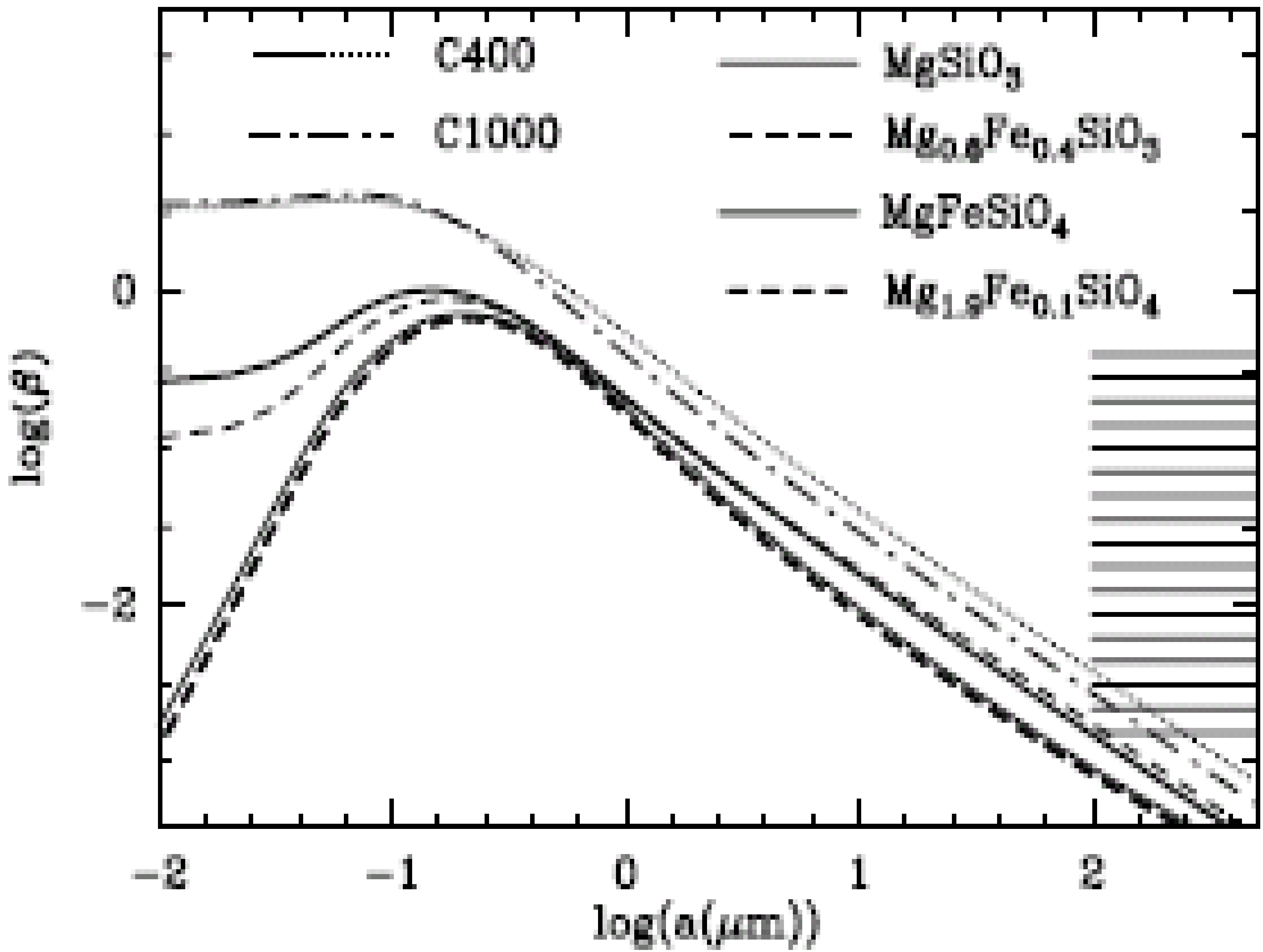
Jiang & Yeh (2009)

- Assume the new dust grains are generated randomly from the ring area (86 to 200 AU)
- Dust grains feel the gravity and radiation pressure from the central star
- Consider effects of chemical composition, different grain-size cut-off, collision interval

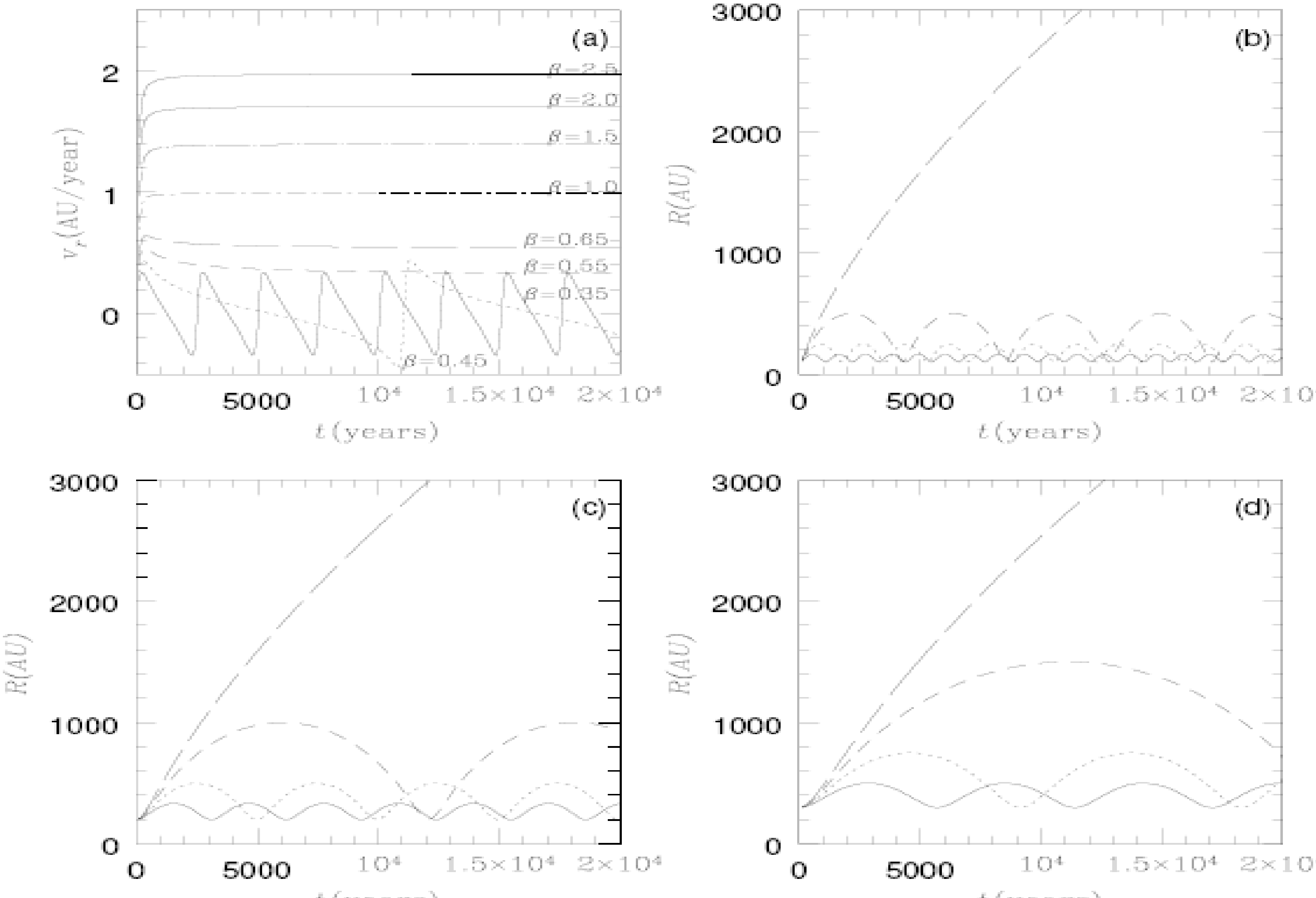
Initial Distributions

$$\frac{dN}{da} = Ca^{-3.5},$$

$$\Sigma_1(R) = \begin{cases} \frac{\Sigma_0}{100^2} & \text{when } 86 \leq R \leq 100, \\ \frac{\Sigma_0}{R^2} & \text{when } 100 < R \leq 200, \end{cases}$$



C400
C1000
$MgSiO_3$
$Mg_{0.6}Fe_{0.4}SiO_3$
$MgFeSiO_4$
$Mg_{1.9}Fe_{0.1}SiO_4$
$\log(\beta)$
$\log(a(\mu m))$
0
−2
−2
−1
0
1
2



(a)
β=2.5
β=2.0
β=1.5
β=1.0
β=0.65
β=0.55
β=0.35
β=0.45
v_r(AU/year)
t (years)
(b)
R(AU)
t (years)
(c)
R(AU)
(d)
R(AU)

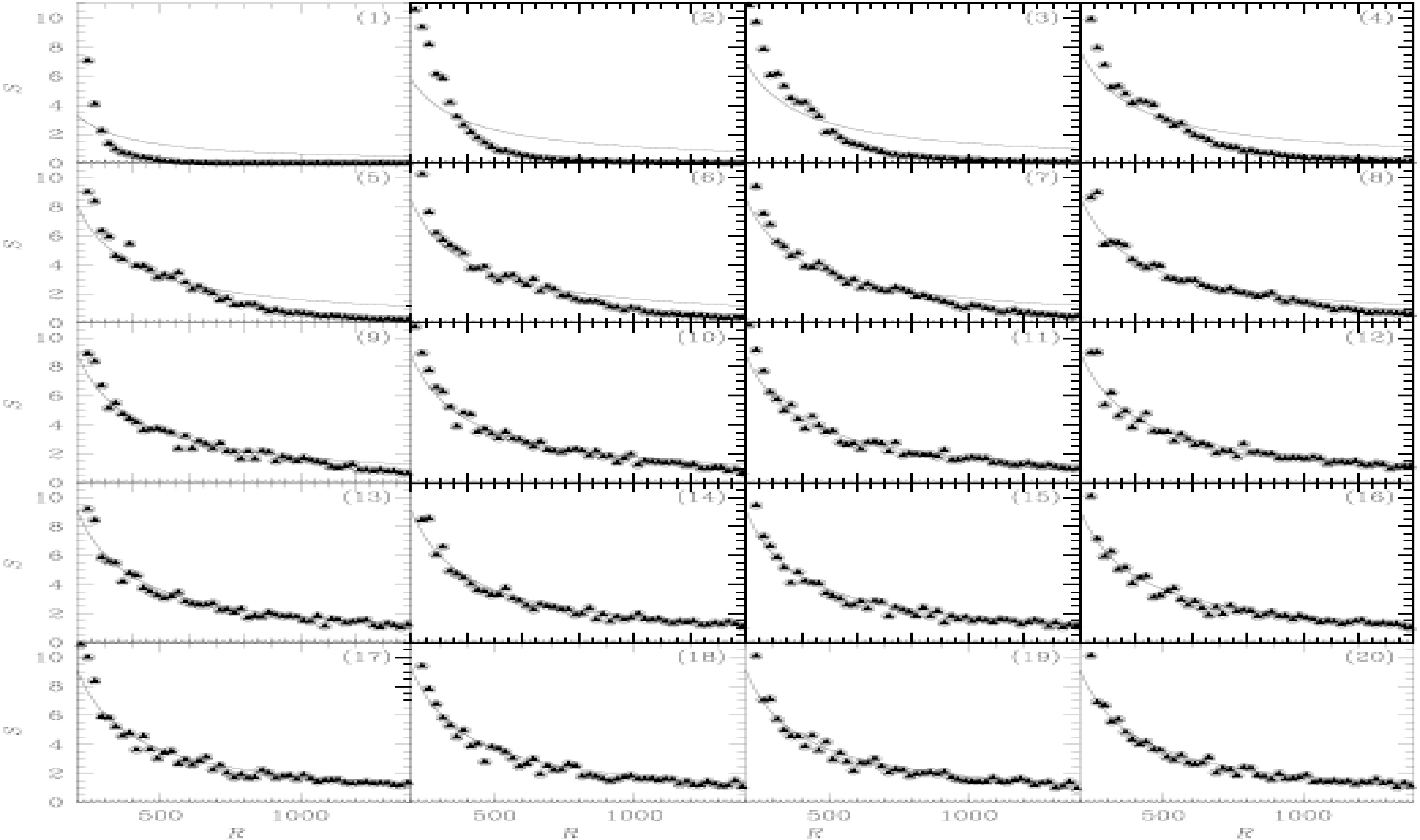
Table 1 The Ingredients of Models

Model	Composition	Grain Density	Time Interval	$a_{\max}$	$\beta_{\min}$
C2S	C400	2.26(g/cm^3)	100 (years)	9.57 (μm)	0.62
C2L	C400	2.26(g/cm^3)	100 (years)	14.04 (μm)	0.42
C3S	C400	2.26(g/cm^3)	1000 (years)	9.57 (μm)	0.62
C3L	C400	2.26(g/cm^3)	1000 (years)	14.04 (μm)	0.42
Mg2S	$MgFeSiO_4$	3.3(g/cm^3)	100 (years)	9.57 (μm)	0.28
Mg2L	$MgFeSiO_4$	3.3(g/cm^3)	100 (years)	14.04 (μm)	0.19
Mg3S	$MgFeSiO_4$	3.3(g/cm^3)	1000 (years)	9.57 (μm)	0.28
Mg3L	$MgFeSiO_4$	3.3(g/cm^3)	1000 (years)	14.04 (μm)	0.19

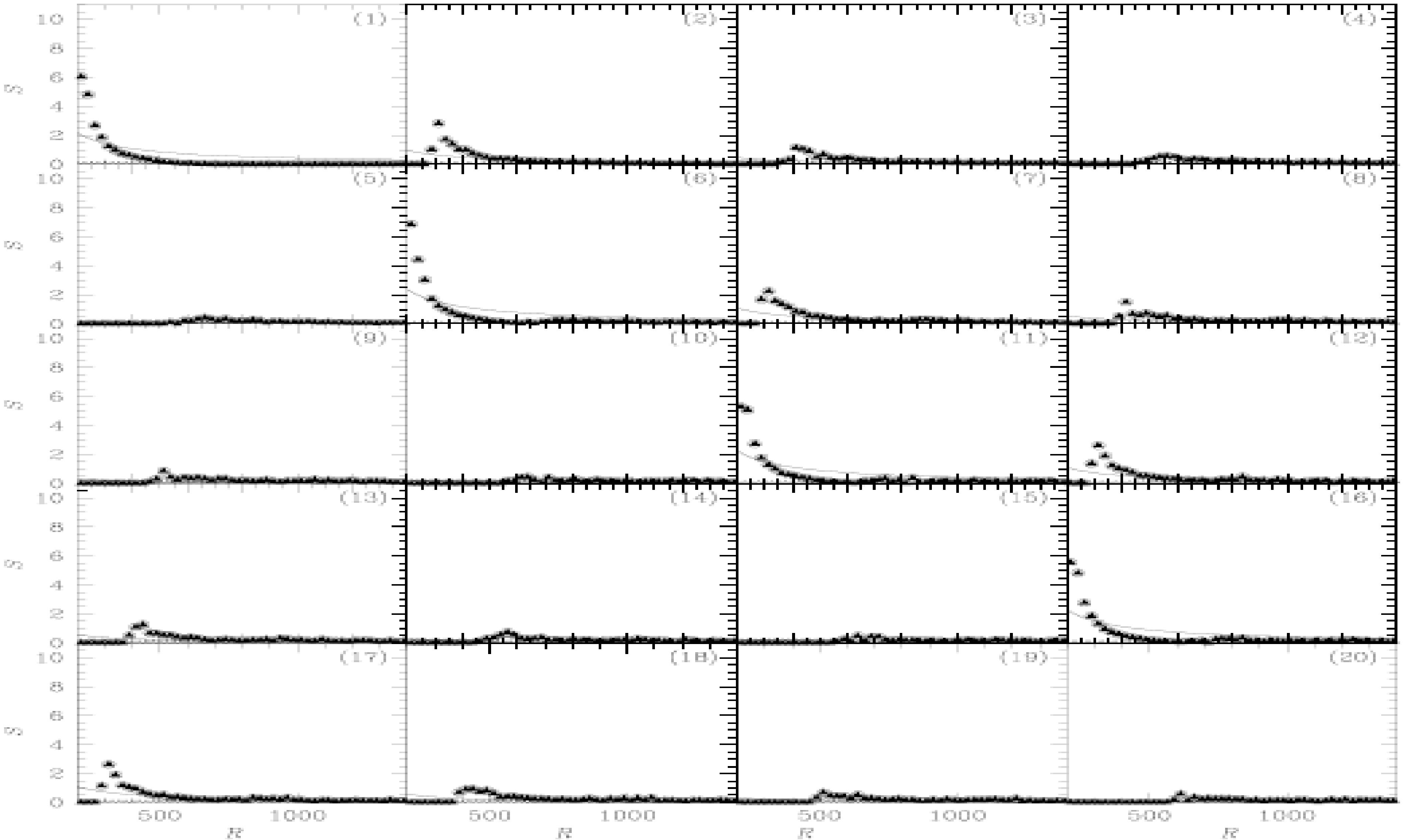
The Grain Number Percentage

Model	smaller grains ($\beta \geq 0.5$)	larger grains ($\beta < 0.5$)
C2S, C3S	100%	0%
C2L, C3L	99.93%	0.07%
Mg2S, Mg3S	99.03%	0.97%
Mg2L, Mg3L	98.88%	1.12%

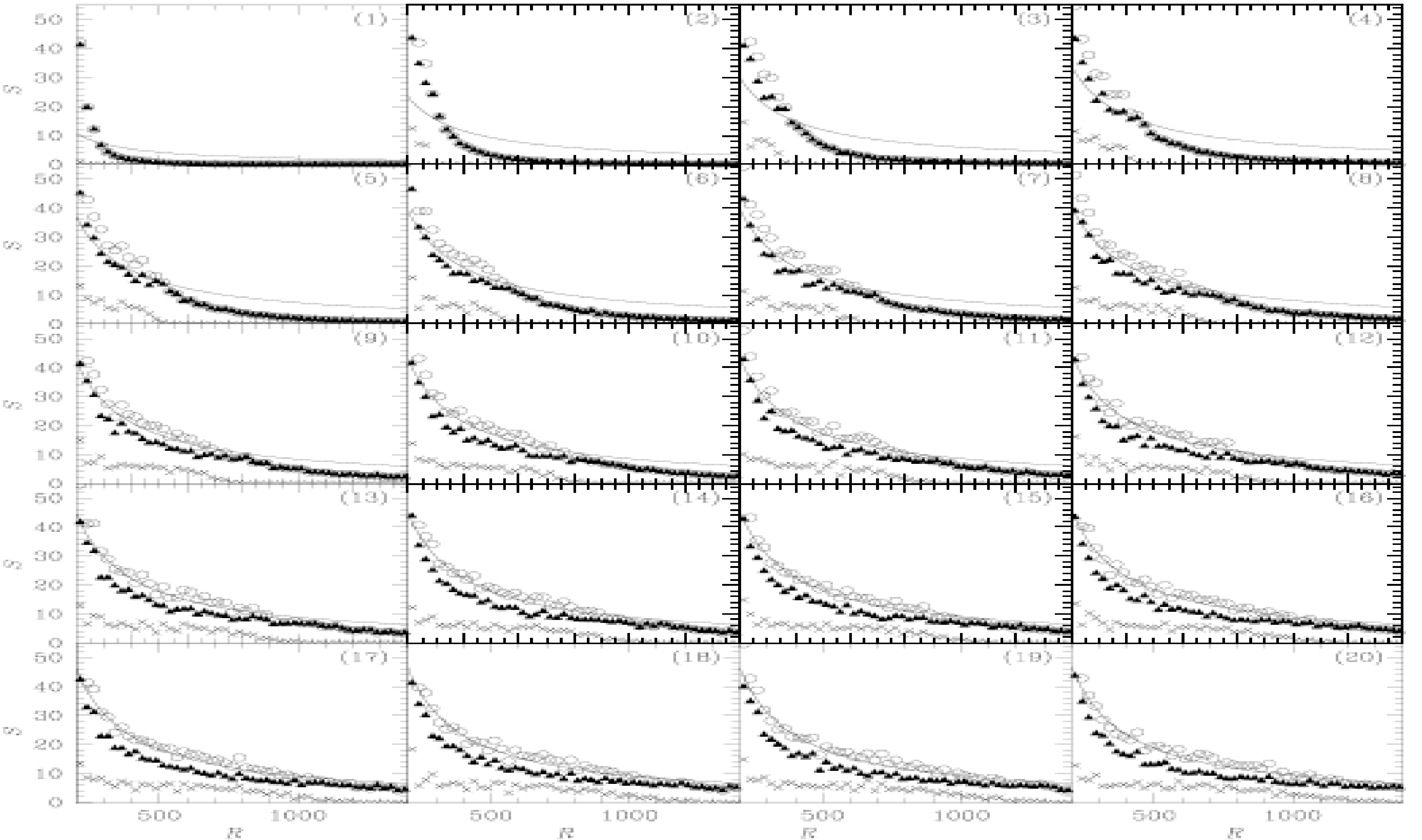
Model C2S



Model C3S

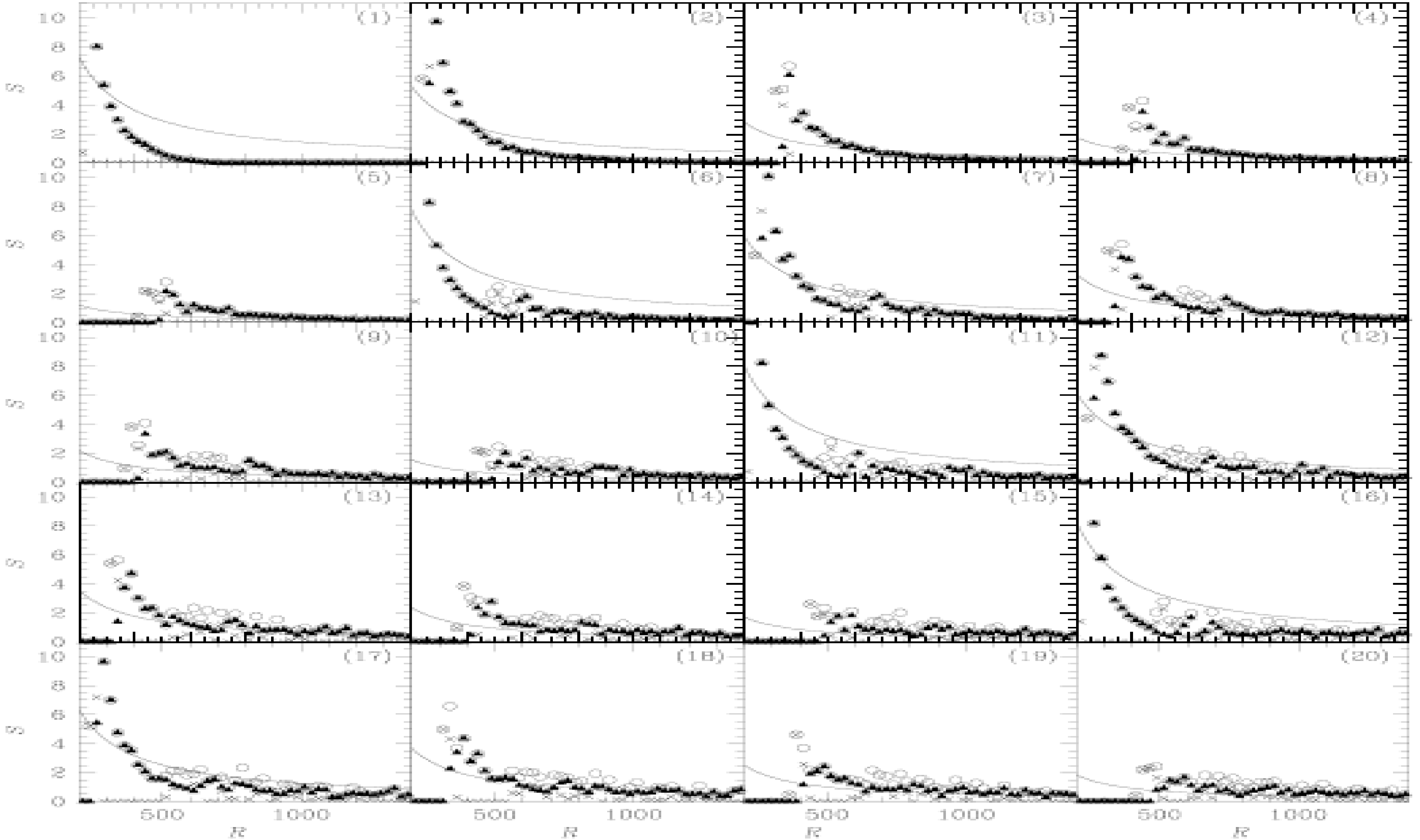


Model C2L

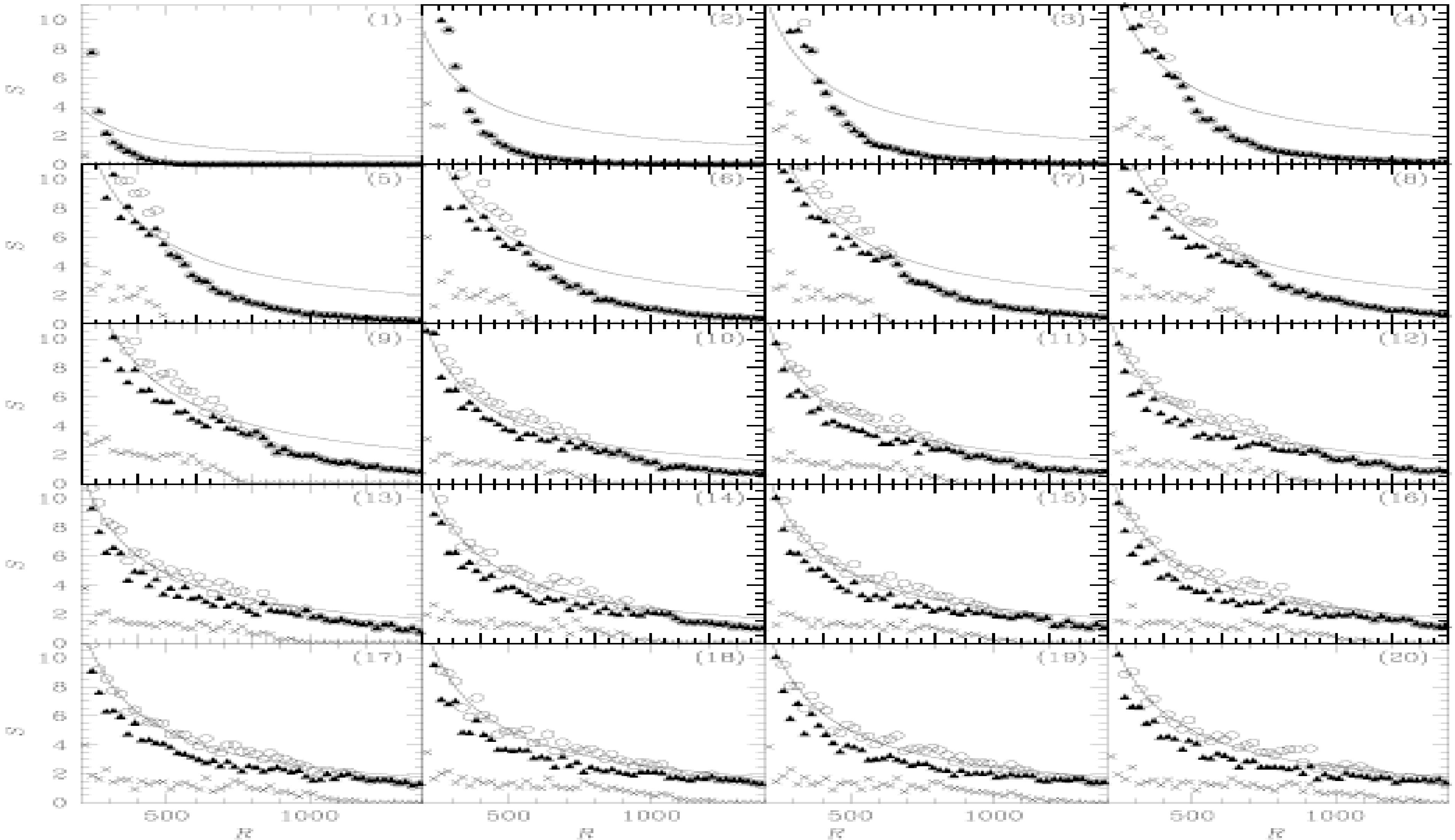


(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)
(14)
(15)
(16)
(17)
(18)
(19)
(20)
S
R
0
10
20
30
40
50
500
1000

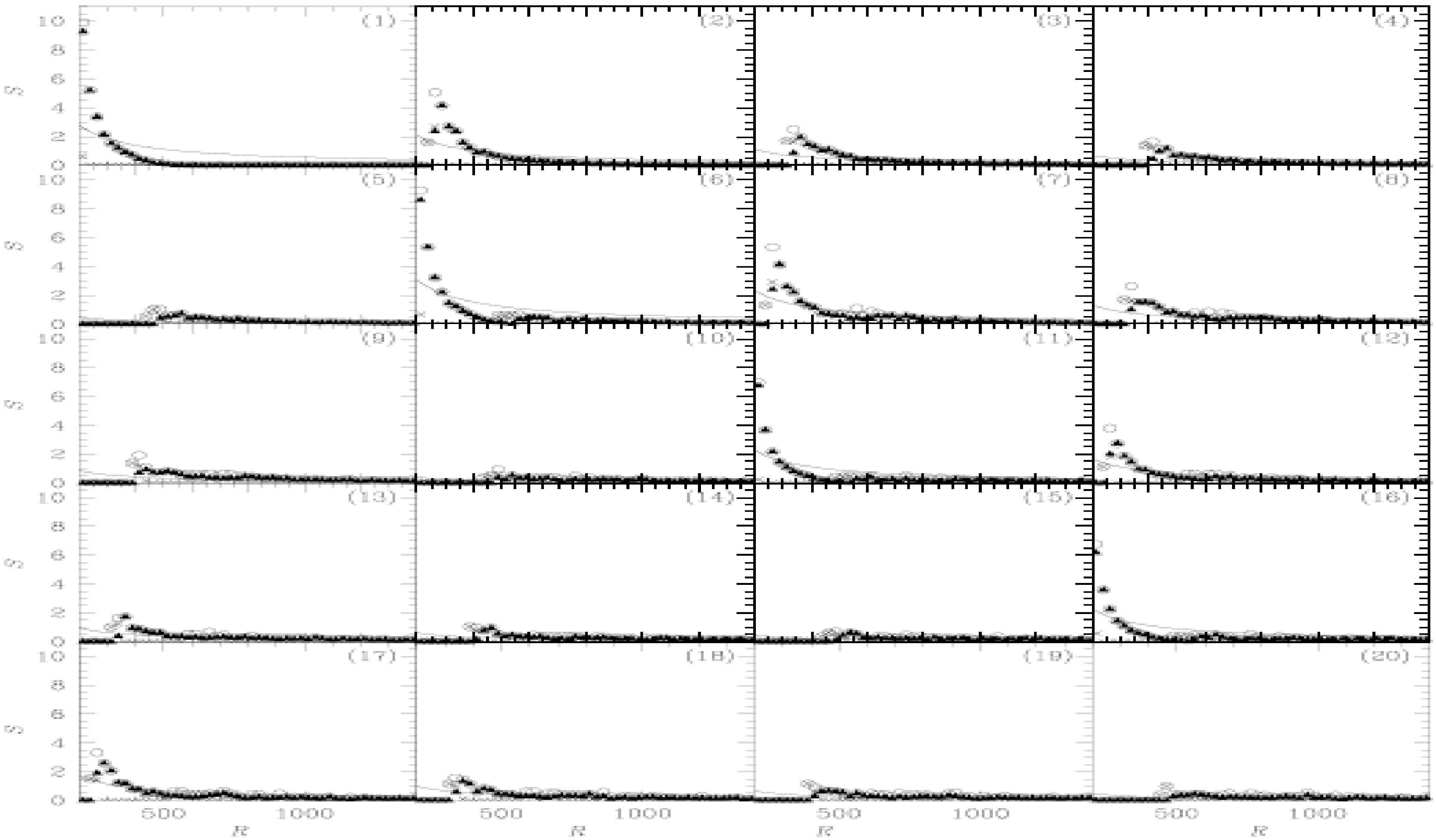
Model C3L



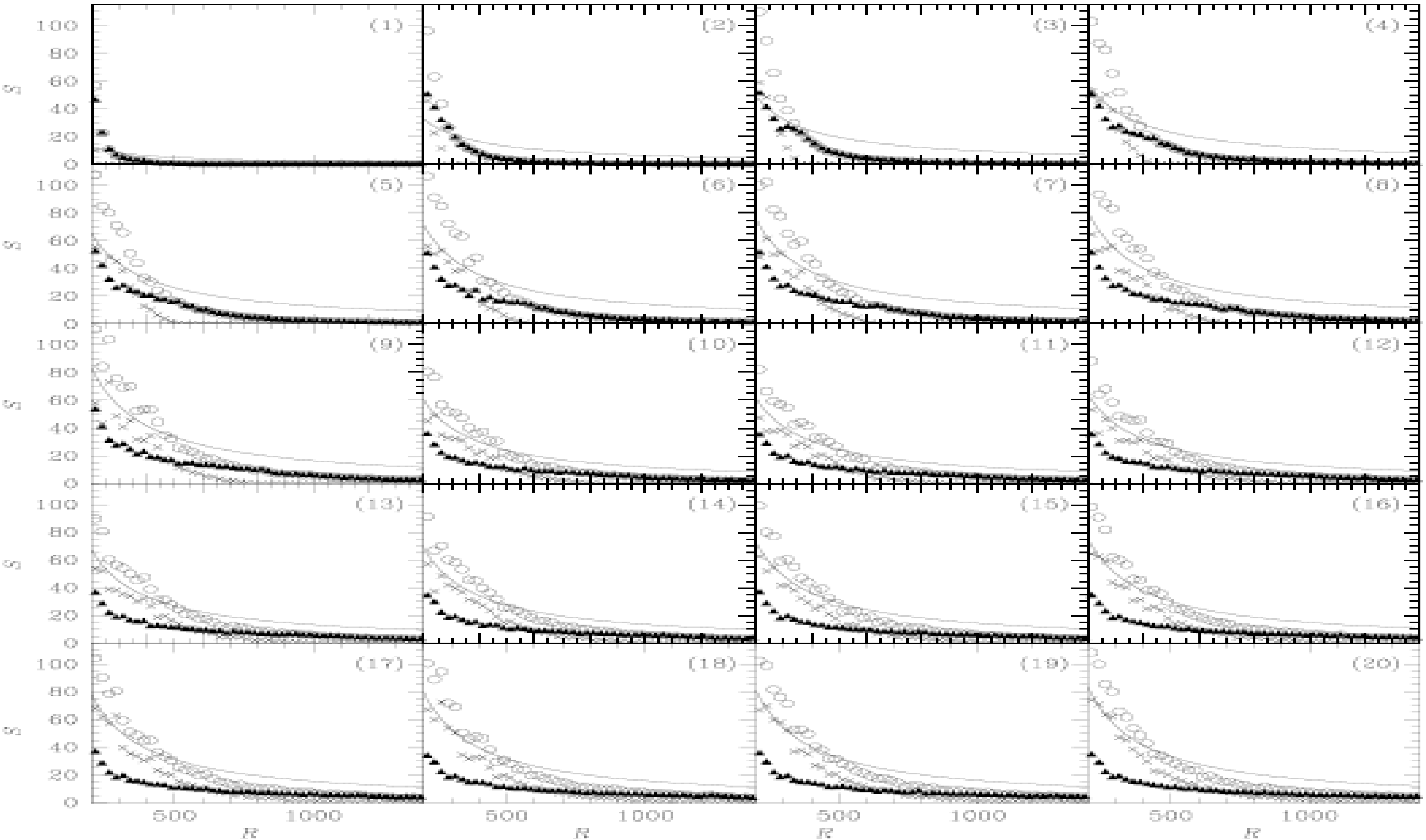
Model Mg2S



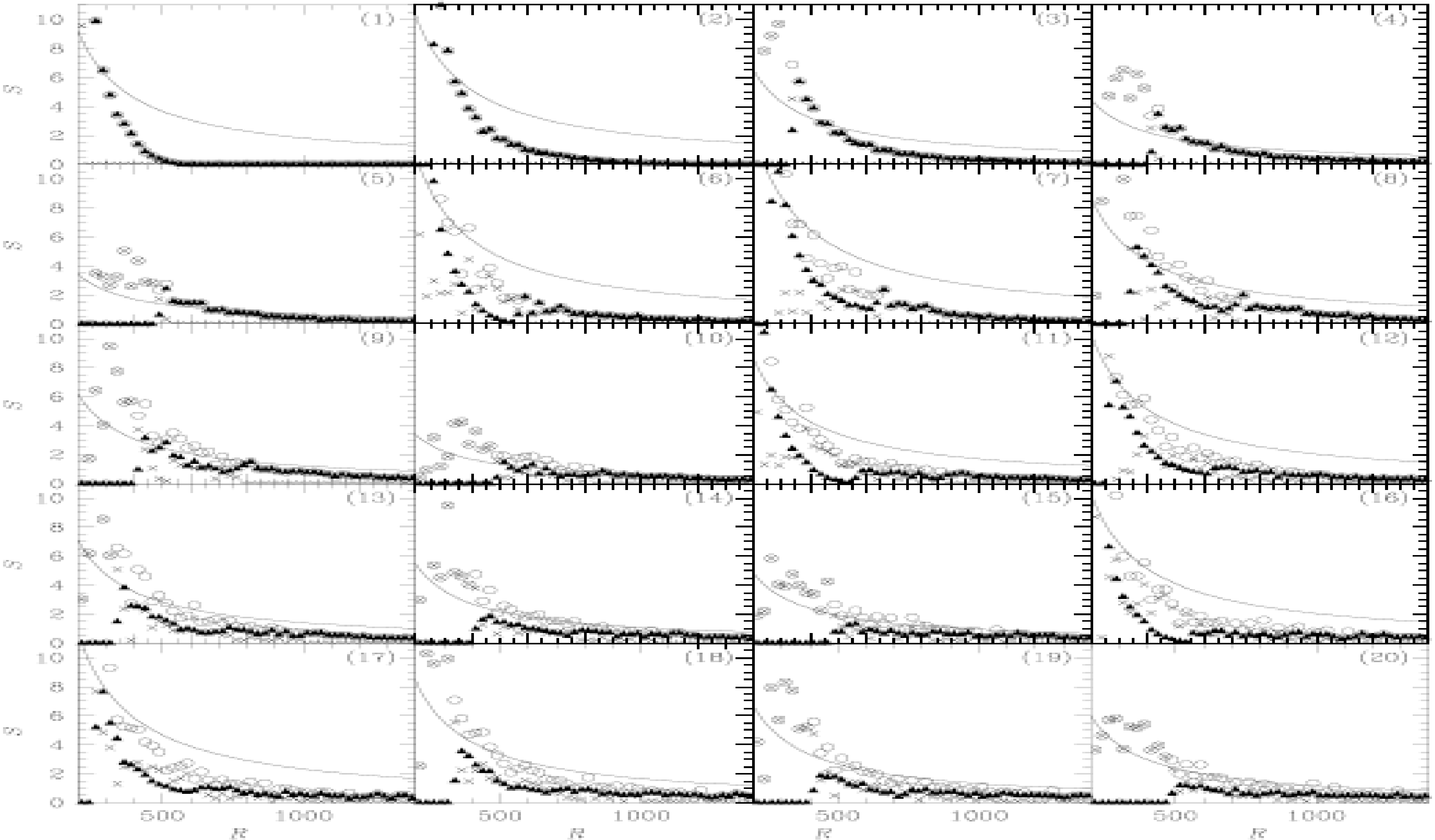
Model Mg3S



Model Mg2L


(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)
(14)
(15)
(16)
(17)
(18)
(19)
(20)
S
R
0
20
40
60
80
100
500
1000

Model Mg3L

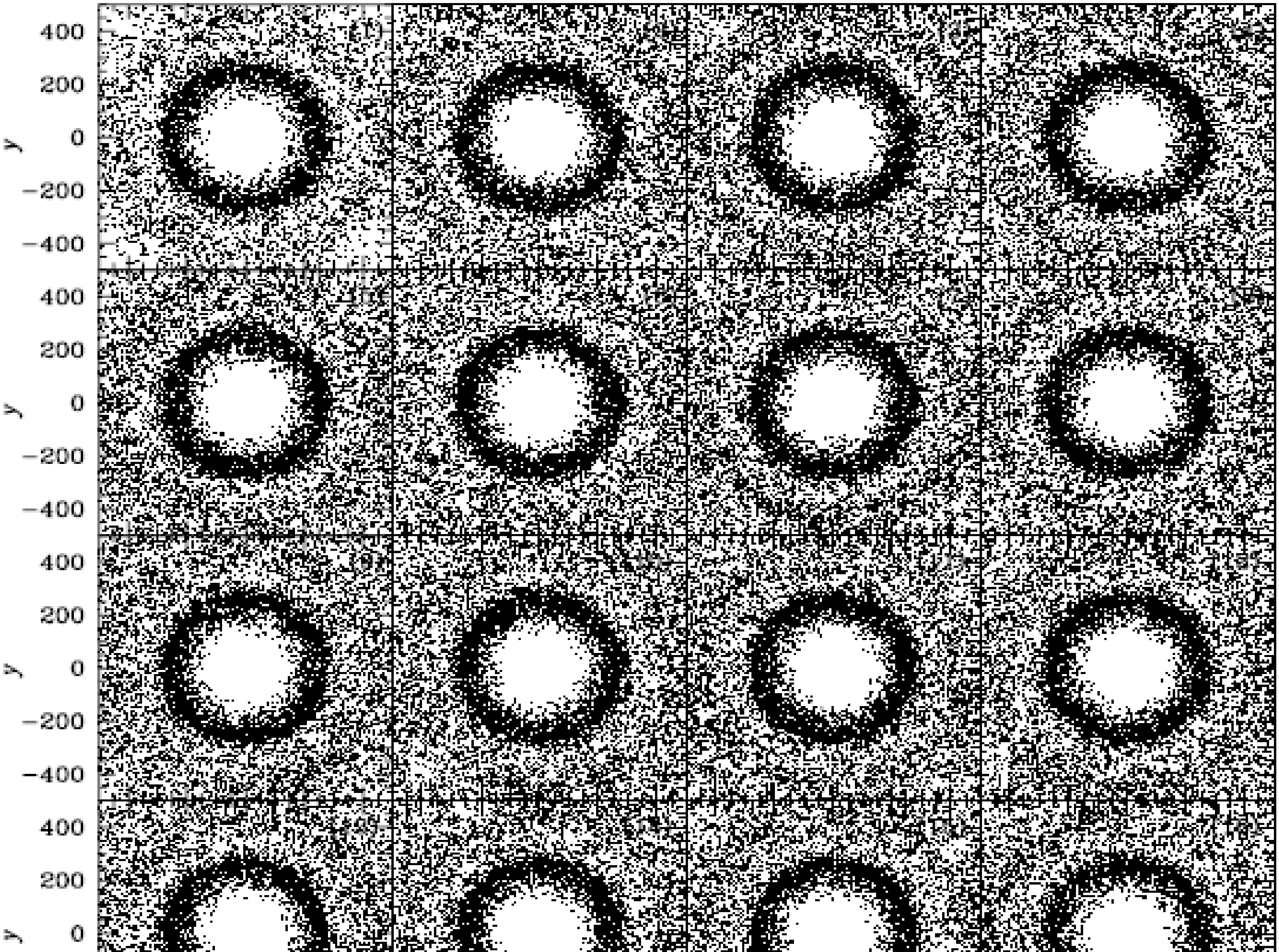


Remarks on blowing-out picture

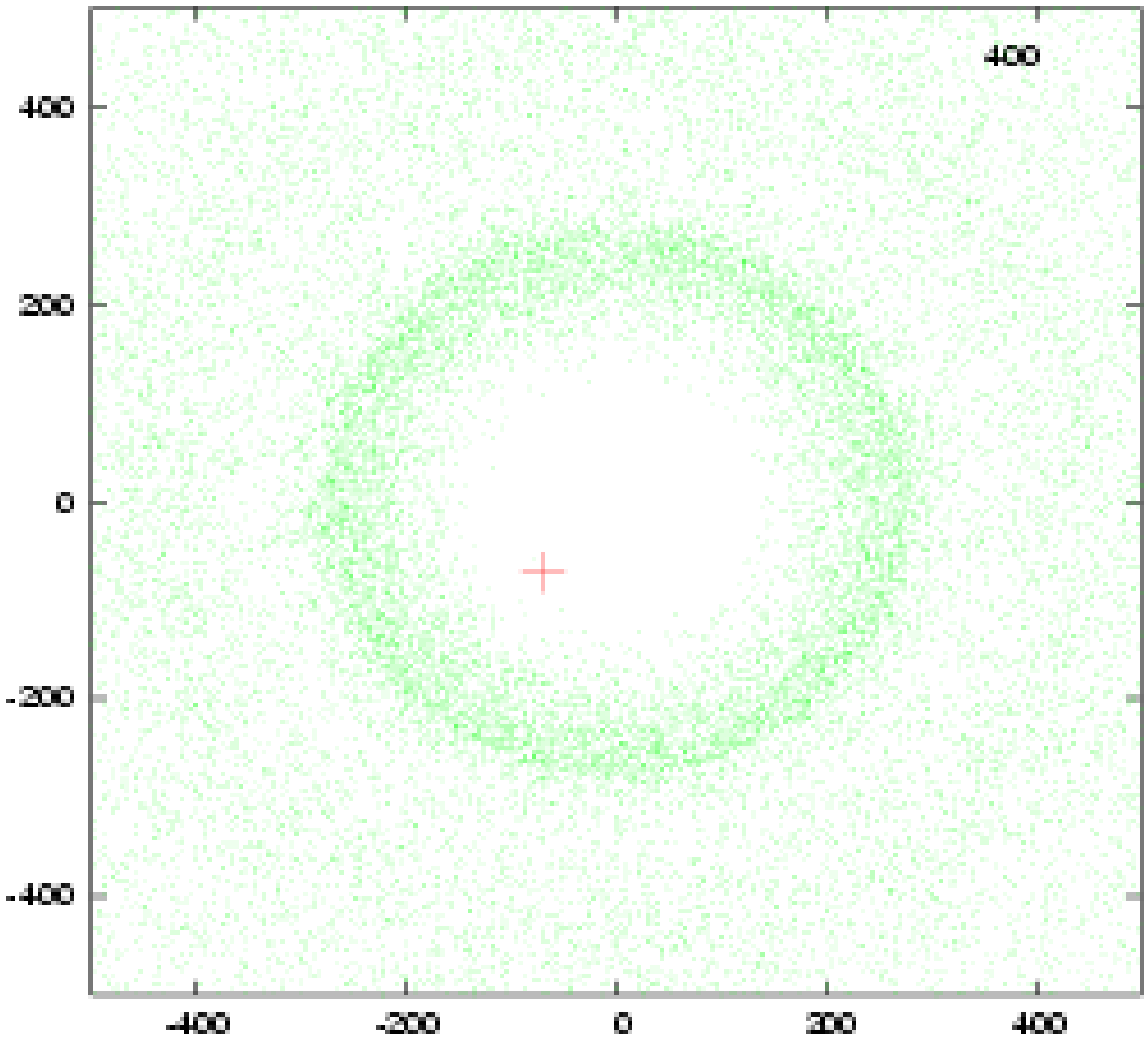
- The self-consistent dynamical model can be constructed for the blowing-out picture
- Model C2S gives the best fit to 1/R profile
- Because the average grain size is smaller
- And the new grains are generated frequently enough
- Generating new grains every 1000 years cannot maintain 1/R profile

The Signature of Planets

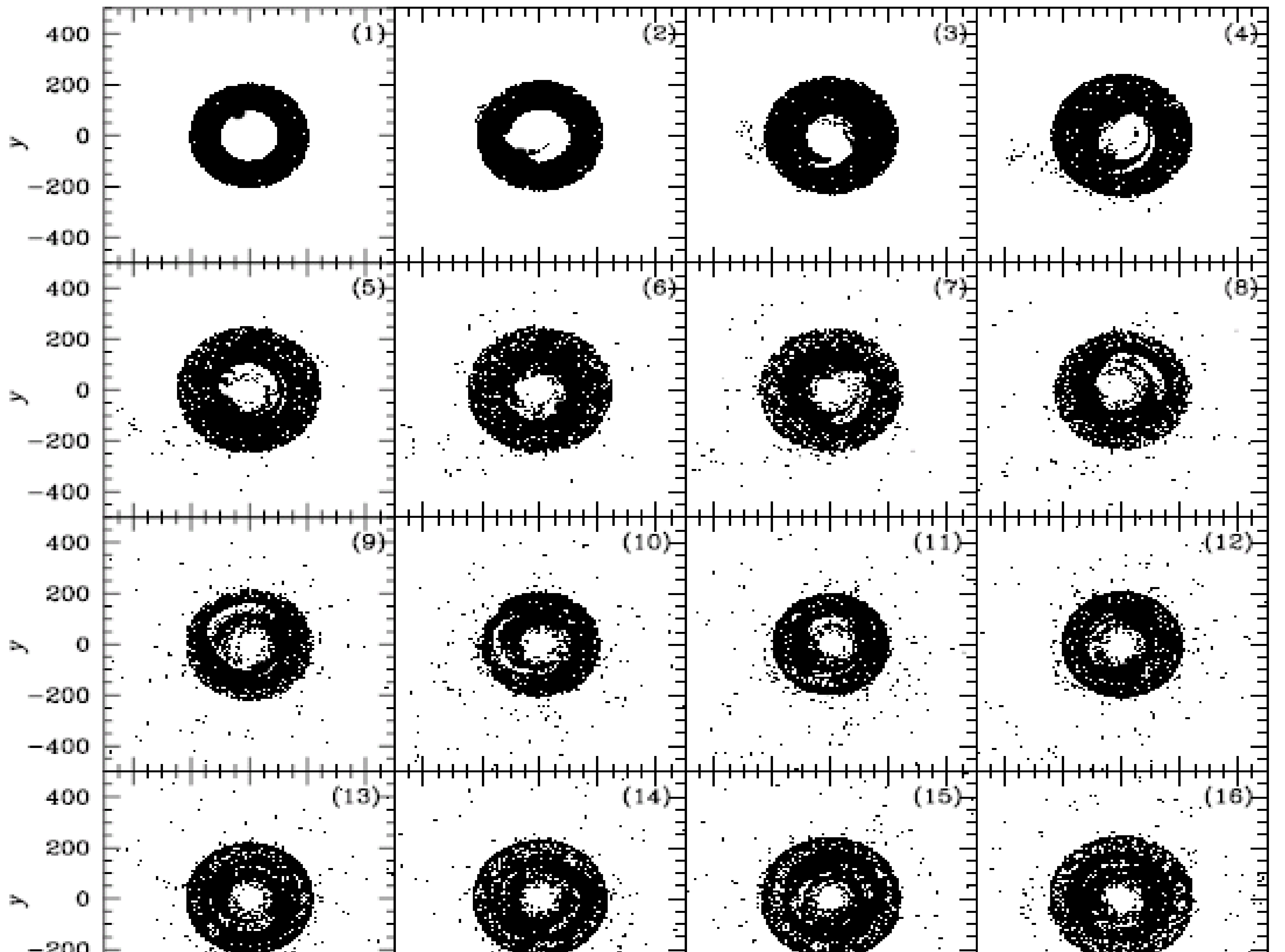
- We also did cases when a planet is added
- No signature of planet in a continuous out-moving dust flow
- The signature is obvious when the dust grain is long-lived
- The planet can be hidden in debris discs !



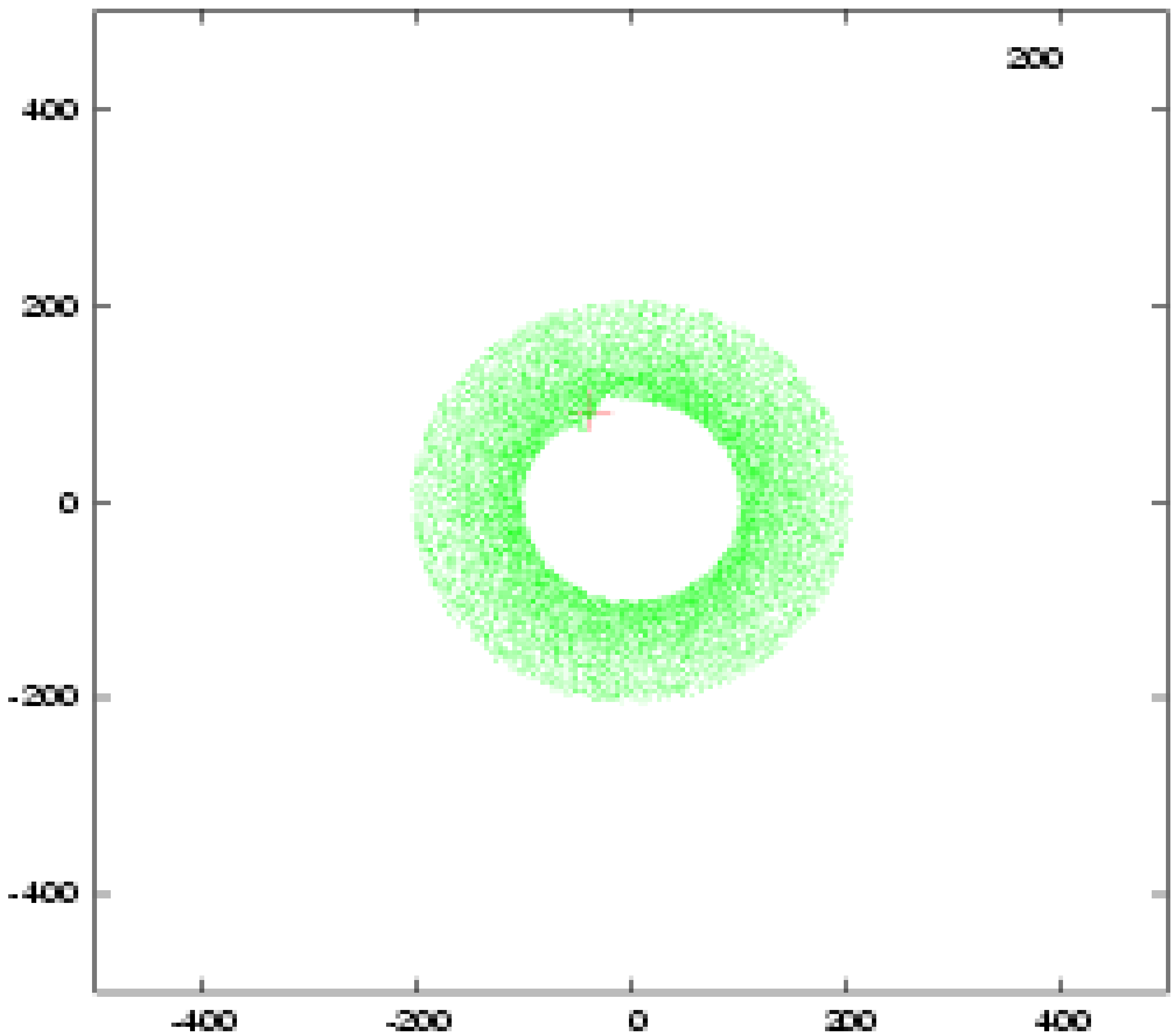
400
200
0
−200
−400
y



400
400
200
0
-200
-400
-400
-200
0
200
400

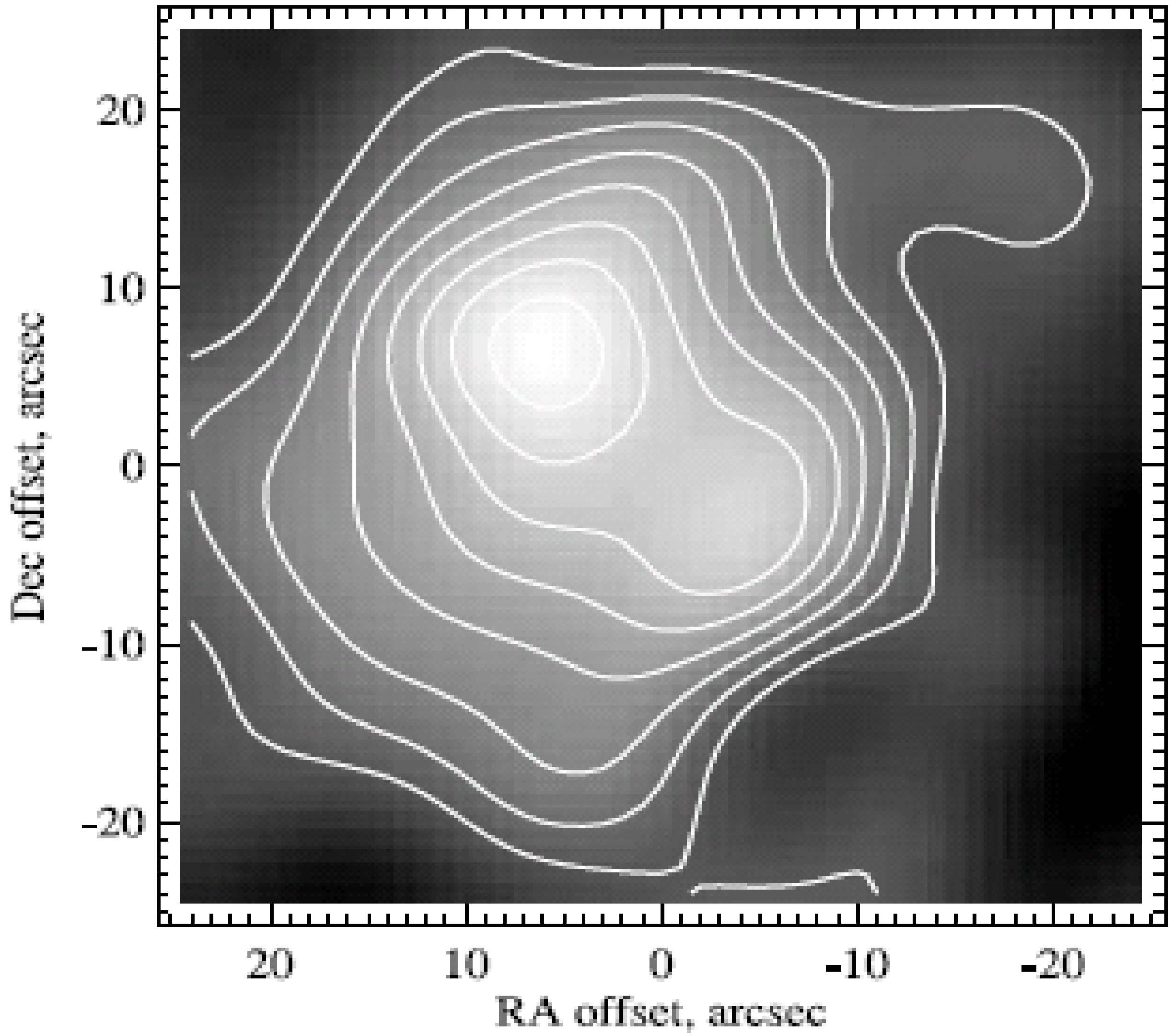


(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)
(14)
(15)
(16)
400
200
0
−200
−400
y

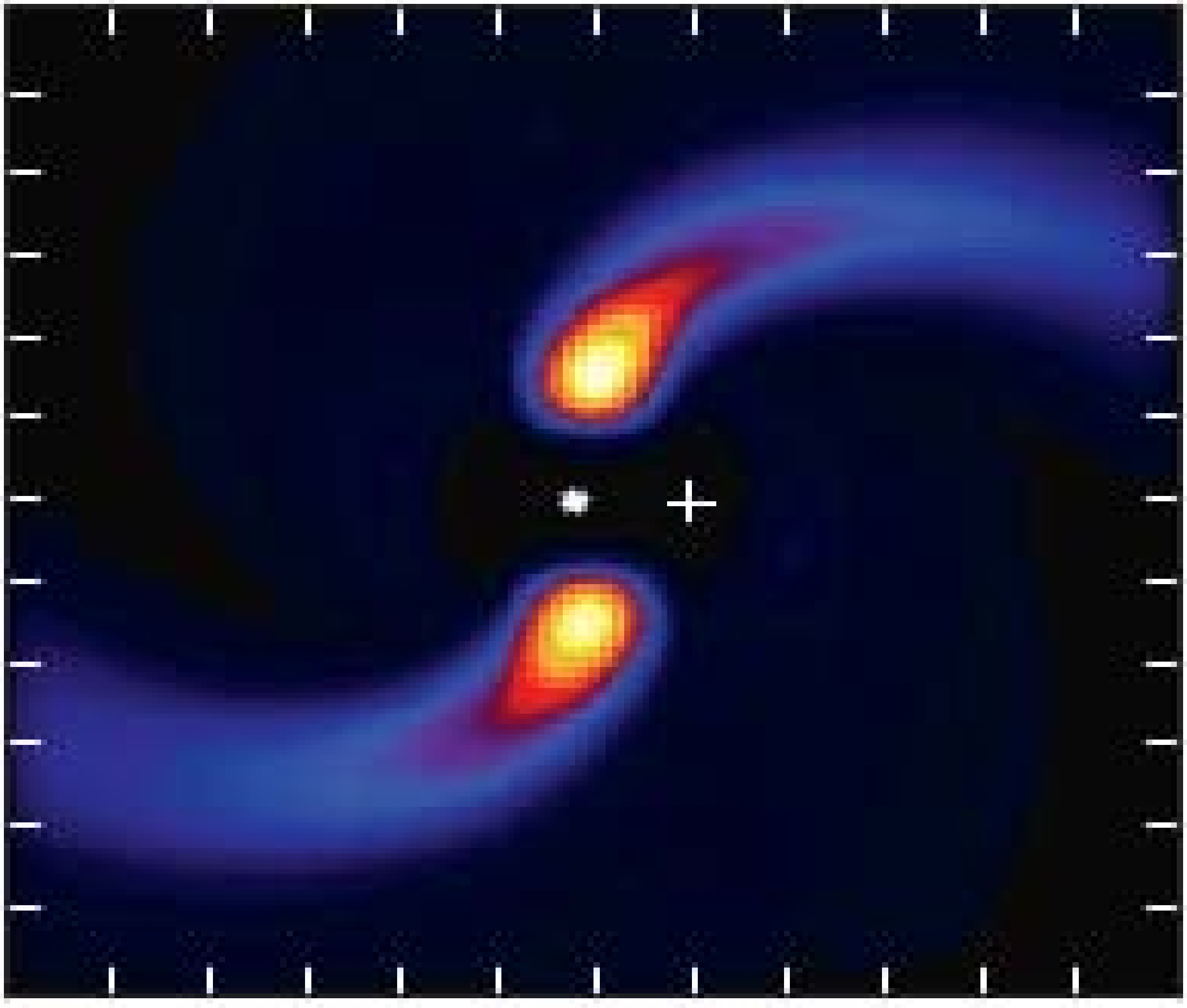


200
400
200
0
-200
-400
-400
-200
0
200
400

Two Clumps (Holland et al. 1998)



Small Grains from One Collision (Wyatt 2006)

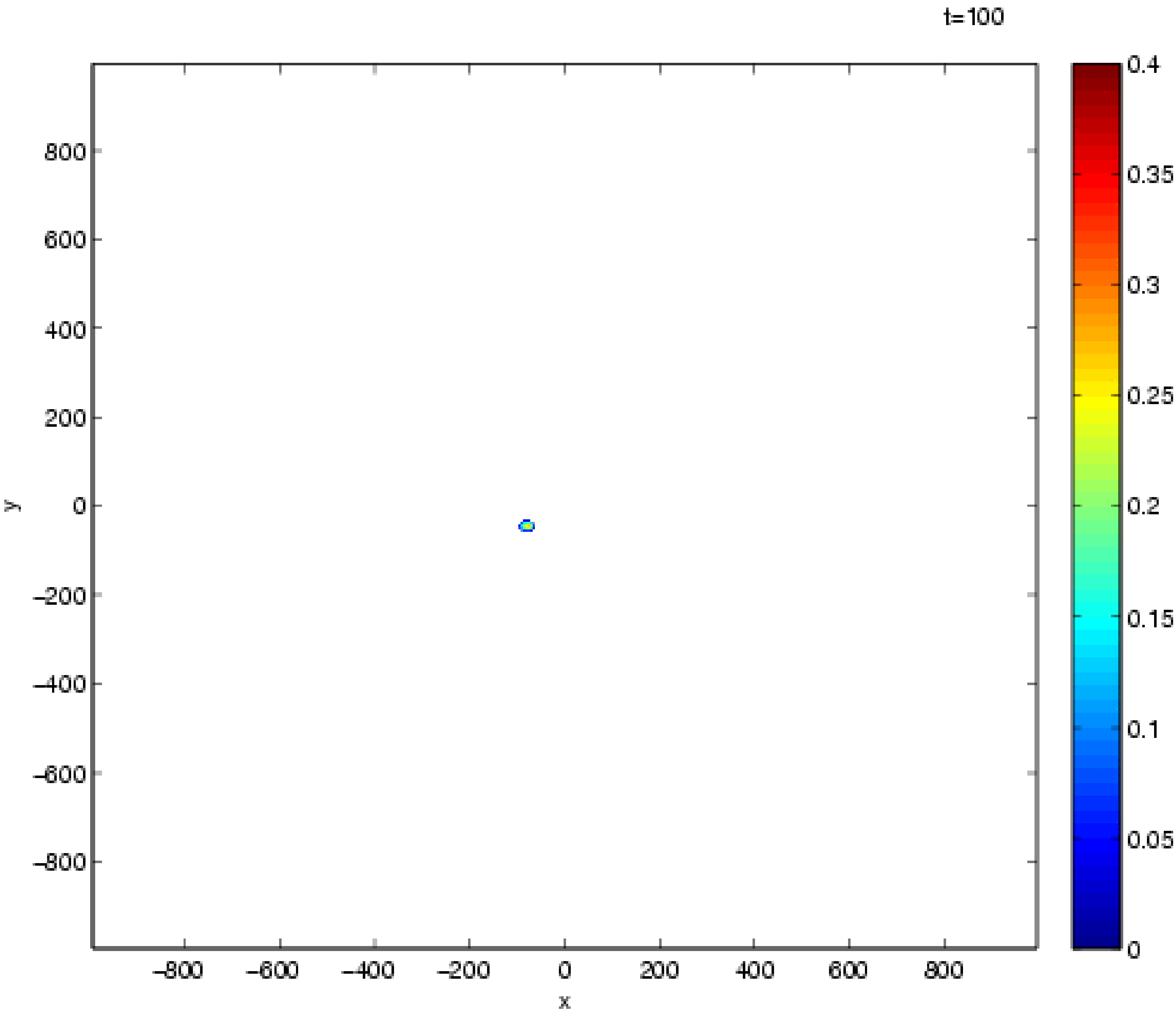


The Vega Puzzle

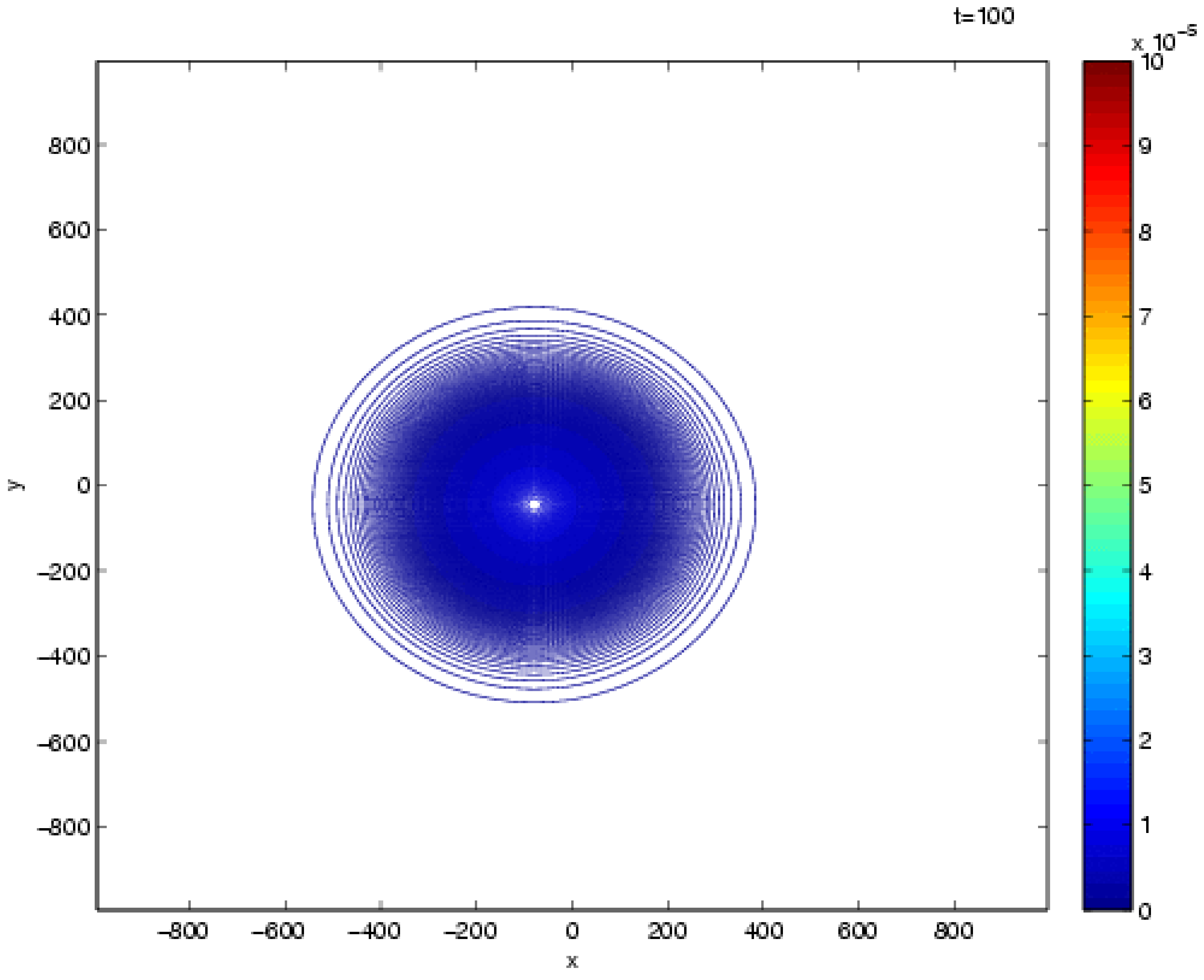
- Dominated by small grains ?
- Axis-symmetric ?
- The mass budget problem ?
- A recent collision and its cascade ?
- Spiral feature ?

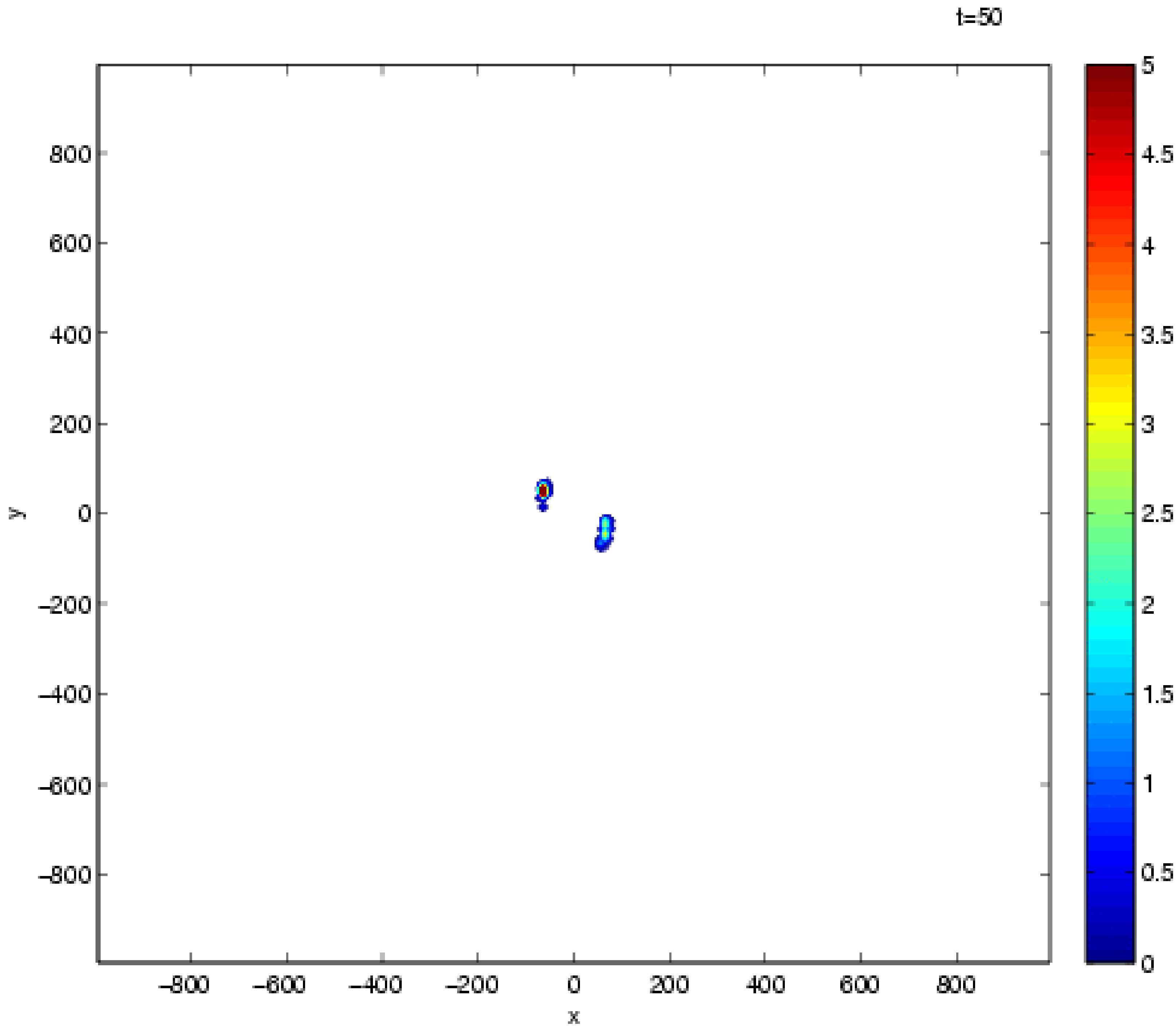
The Recent Work

- Two clumps rotate with a planet
- Assume collisions happen within two clumps
- Planetesimals within the clumps might collide with others, produce small grains

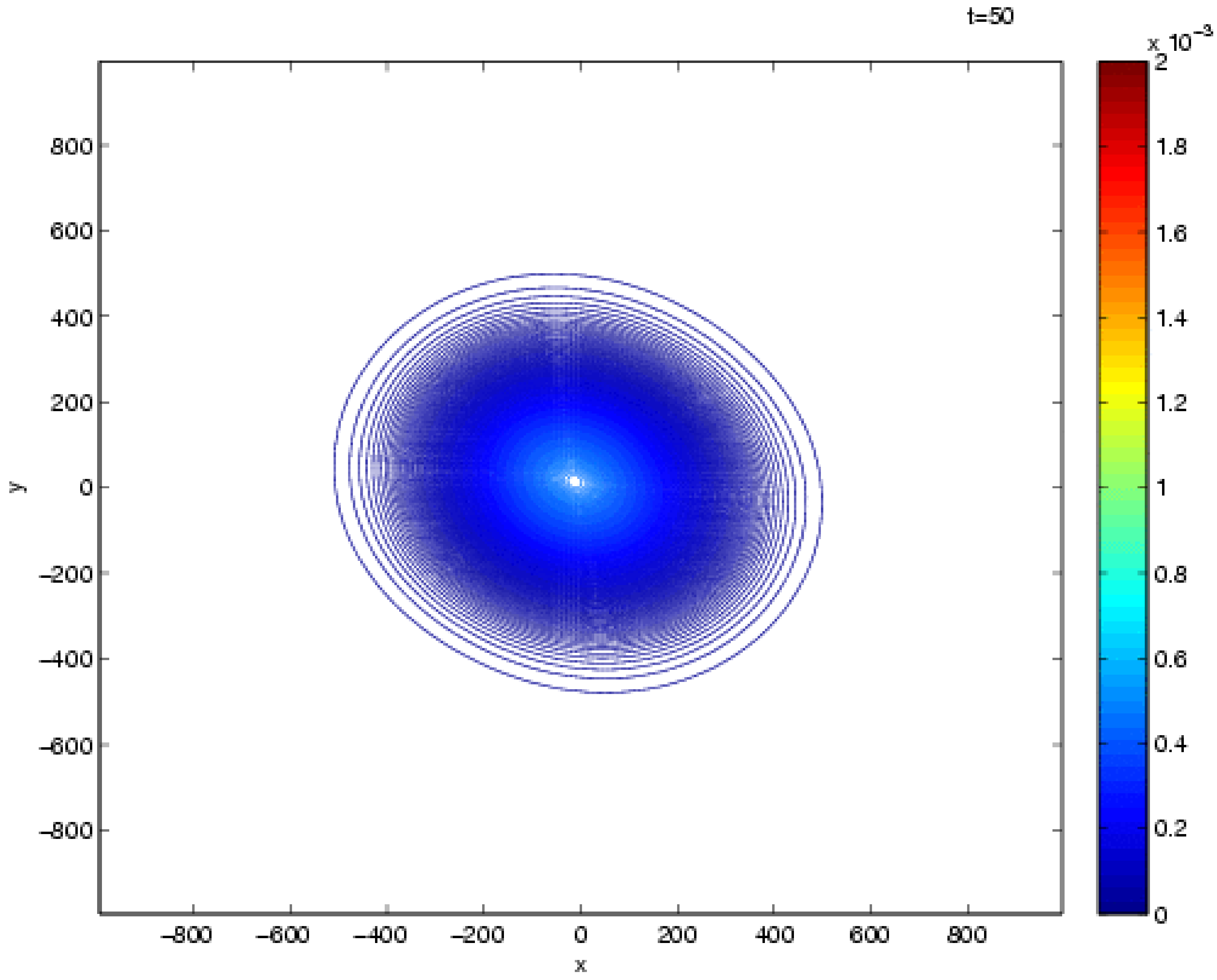


t=100
800
600
400
200
0
−200
−400
−600
−800
y
−800
−600
−400
−200
0
200
400
600
800
x
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0


t=100
x 10^-5
10
9
8
7
6
5
4
3
2
1
0
800
600
400
200
0
-200
-400
-600
-800
y
-800
-600
-400
-200
0
200
400
600
800
x



t=50
800
600
400
200
0
−200
−400
−600
−800
y
−800
−600
−400
−200
0
200
400
600
800
x
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0



t=50
x 10^-3
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
800
600
400
200
0
−200
−400
−600
−800
y
−800
−600
−400
−200
0
200
400
600
800
x

Remarks

- We are producing more realistic results than those in Jiang & Yeh (2009)
- A model which can solve the Vega Puzzle might exist
- Further advanced observations will be important

Thank You